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# Predication of the behaviour of bulk materials in the design and operation of bulk handling and processing plants

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## Abstract

It is very dangerous to assume or extrapolate anything when it comes to bulk material properties and behaviour. Traditional methods for flow prediction, such as hand calculation or even just relying on past experience, require assumptions to be made about the bulk material properties and flow. Although these materials may have generic names and possess similar properties (e.g. coal, iron ore), they can all behave quite differently under dynamic conditions. What we end up designing for one part of the plant may be quite different to what is needed in another part of the plant, which may be handling or processing a different size fraction, say. The consequences of making too many assumptions can be quite serious as illustrated by flow blockages in handling and processing operations, such as conveyor transfers, chutes, ship loading, etc. A common concern when applying DEM to bulk flow problems is determining how you set the material, interaction and geometric properties of your particle elements to provide you with accurate results. DEM, like with all forms of modelling, is a mathematical representation of the real world. A real material can consist of many millions/billions of individual elements, each one with its own shape. The big question is how can you go from your real material to a DEM element equivalent; such that the bulk properties and behaviour observed in the simulation sufficiently represent that seen in the real world? Figure 1 shows how this is to be achieved.



## Keywords

handling, operation, design, processing, materials, bulk, behaviour, plants, predication


## Disciplines

Engineering | Science and Technology Studies


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# Prediction of the behaviour of bulk materials in the design and operation of bulk handling and processing plants

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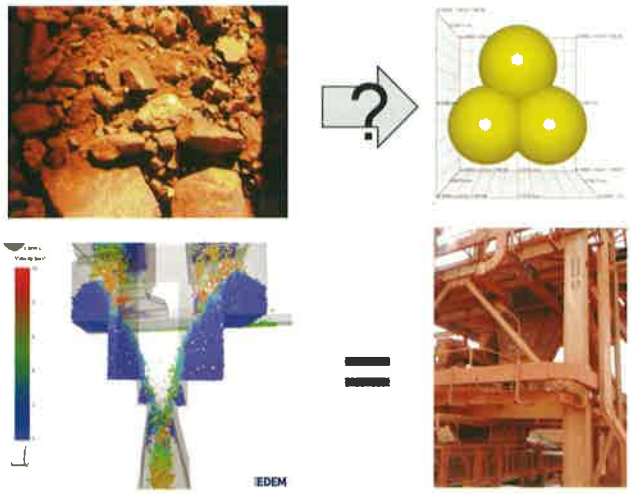


*Figure 1: Linking an EDEM Material Model to physical reality.*

## 1. Introduction

It is very dangerous to assume or extrapolate anything when it comes to bulk material properties and behaviour. Traditional methods for flow prediction, such as hand calculation or even just relying on past experience, require assumptions to be made about the bulk material properties and flow. Although these materials may have generic names and possess similar properties (e.g. coal, iron ore), they can all behave quite differently under dynamic conditions. What we end up designing for one part of the plant may be quite different to what is needed in another part of the plant, which may be handling or processing a different size fraction, say. The consequences of making too many assumptions can be quite serious as illustrated by flow blockages in handling and processing operations, such as conveyor transfers, chutes, ship loading, etc.

A common concern when applying DEM to bulk flow problems is determining how you set the material, interaction and geometric properties of your particle elements to provide you with accurate results. DEM, like with all forms of modelling, is a mathematical representation of the real world. A real material can consist of many millions/billions of individual elements, each one with its own shape. The big question is how can you go from your real material to a DEM element equivalent; such that the bulk properties and behaviour observed in the simulation sufficiently represent that seen in the real world? Figure 1 shows how this is to be achieved.

The EDEM Material Model has been developed specifically for this purpose via a new collaboration between Bulk Materials Engineering Australia (BMEA) and DEM Solutions Ltd. (DEMSL). This paper will address the following questions:

- What is a calibrated EDEM Material Model?
- What is the methodology to obtain a calibrated EDEM Material Model?
- How much calibration is necessary?

## 2. What is a calibrated EDEM material model?

A commonly asked question in industry is: What inputs into my simulation should I use so that the bulk flow behaviour in the simulation represents that of the real material? In all applications the risk is high when making design decisions based on simulation results without having an answer to this question. The solution to this problem is to develop a calibrated EDEM Material Model as depicted in Figure 2. Some details and examples of the calibration technology have been presented recently [1-3]

The EDEM Material Model is a particle-scale model that generates an approximation of bulk material behaviour that is sufficient for the particular engineering design requirements. But what do we mean by this? Usually people think of only which interaction parameters they need to input to produce the correct behaviour, as shown in the upper left-hand part of Figure 2. However, the EDEM Material Model is not just about material properties and interaction parameters. It also includes the element shape and size distribution (upper right-hand) appropriate for the particular bulk material. In addition, the appropriate physics is represented by contact models (lower right-hand) which govern how the bulk material interacts with itself and the surrounding machinery. Finally, at the heart of the EDEM Material Model is calibration and verification of all of these against ***real*** physical tests. All of these components are combined to produce a ***fit-for-purpose*** flow behaviour model. The aim is not to fully characterise a material, but rather to provide a material model that is sufficiently capable of modelling the real bulk properties and flow behaviour in an EDEM simulation.

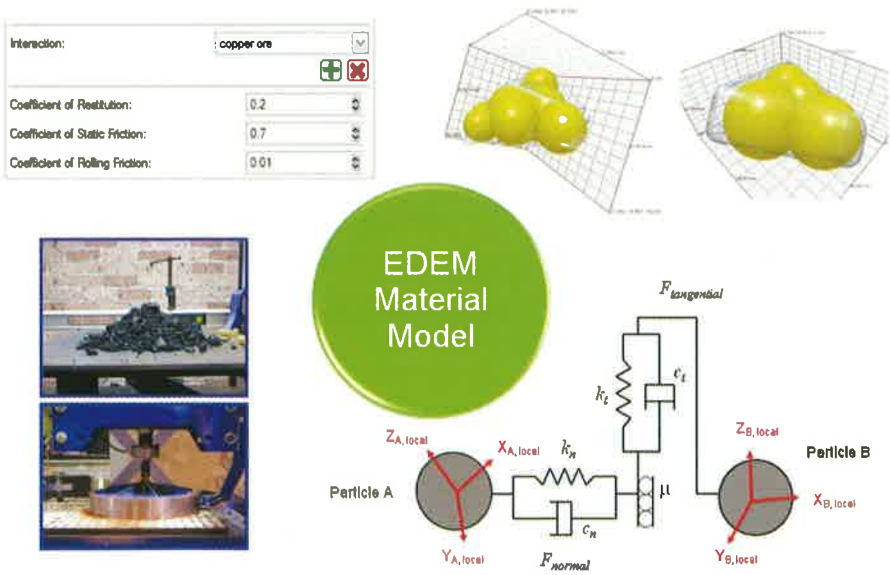


*Figure 2: EDEM Material Model.*

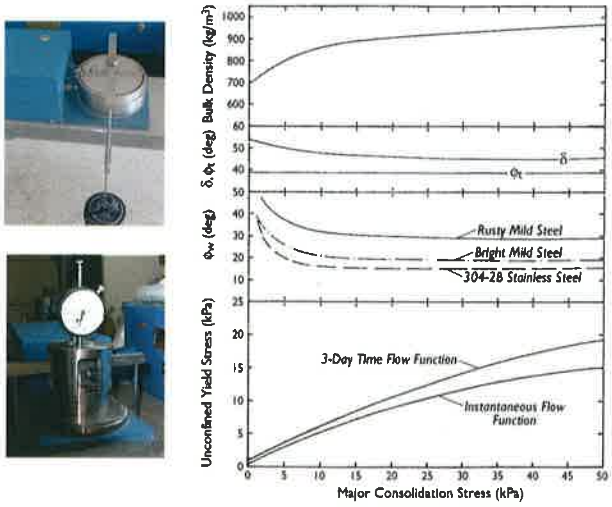


*Figure 3: Standard bulk material flow property tests and typical results (used for static or quasi-static applications, such as bins and hoppers).*

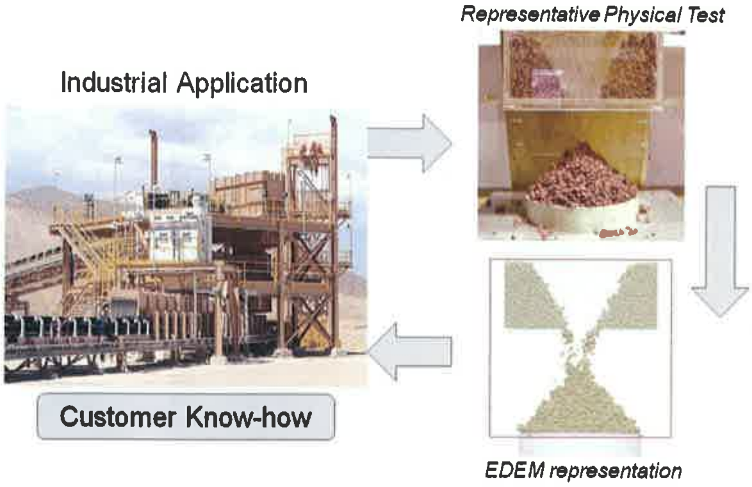


*Figure 4: EDEM Material Model calibration philosophy.*

We often get asked about whether current industry standard flowability tests [4] (such as shear test data depicted in Figure 3) can be used for EDEM Material Model calibration. Although this information is useful in bulk material engineering, such tests provide static or quasi-static information about the bulk material which is not sufficient for dynamic flow situations, such as transfer chutes. Because of the nature of these standard tests, often there are limits on particle size, so the sample tested is not the same as the material in the bulk flow design situation. Above all, the standard test observables are not readily linked to the EDEM Material Model. The next section details a methodology for selecting appropriate physical tests, which will provide the dynamic bulk flow behaviour, and are readily translated into an EDEM Material Model.

## 3. EDEM material model calibration methodology

DEM Solutions (DEMSL) and Bulk Materials Engineering Australia (BMEA) have worked with clients on a range of calibration exercises, and have developed a methodology that serves as a pragmatic alternative to traditional calibration approaches. The image below outlines the methodology.

EDEM provides a way to verify and visualise bulk solids flow. With properly calibrated bulk material models, EDEM can be deployed directly into the engineering design process. This allows the engineer to check potential designs quickly before building physical prototypes. In order to be able to do this though, it is essential that a calibrated material model be developed early in the design cycle based on the real bulk material at various flow conditions that will be present in the final application. BMEA has created a series of physical bulk material tests which allow us to understand how a bulk solid flows and create an EDEM Material Model from physical data.

The selection of appropriate physical tests is critical to ensure that the calibrated EDEM Material Model will produce a fit-for-purpose behaviour when deployed in the simulation of the industrial application. Use of traditional material testing devices has been shown to be an unreliable approach for generating suitable data to calibrate an EDEM Material Model for industrial use. The key reason for this is that the condition under which the material is tested is not representative of the flow regimes observed at the industrial scale. In addition, the real material is often processed in advance of testing to the point that it can be accommodated by the scale of traditional tests, such as standard shear tests. Finally, the outputs from traditional tests do not readily correlate with the inputs required for a DEM simulation. Rather than relying on the data generated by the traditional tests, a suitable test for use in the calibration of an EDEM Material Model (as shown in Figure 4) is one that:

- Uses the real material as observed on site, not pre-processed for testing.
- Recreates the typical flow regime and bulk behaviour seen in the application.
- Provides comparative observable measurements between experiment and simulation.

BMEA have developed a range of testing devices that allow everything from particle size and shape measurements, to dynamic experiments to be performed. The range of tests available means that material bulk flow behaviour as well as interaction with equipment can be observed and measured. Selection of the appropriate tests is made on a case-by-case basis to ensure that those flow regimes specific to an industrial application are replicated sufficiently.

To illustrate the process of selecting appropriate physical tests, we will use a transfer chute example shown in Figure 5. The aim of this case study is to demonstrate the procedure used to develop numerous EDEM material models for the products being conveyed at various moisture contents (from 0% to maximum strength). Key aspects of this case study are as follows:

- Trihydrate and monohydrate grade bauxite are being conveyed through a transfer. The trihydrate is more difficult to handle as it has finer particles which absorb more water and increases its internal strength.
- The design rate is around 3400tph, but actual tonnages vary from 2,600 to 3,200tph.
- A poorly designed chute results in non-ideal flow and material build-up from a V-plate, which restricts flow. The chute also contains large rock-box ledges, which decelerate the flow stream but also compact the material.
- As a result, blockages occur in the lower chute.

EDEM was deployed to identify flow problems and verify EDEM material models by comparing results against observations from the site. Once the basic flow properties of a product are measured, the next stage is the selection of suitable bench-scale tests, which possess similar bulk behaviour where contact parameters can be calibrated. If we are to propose a rock-box chute design, then it would be appropriate to select a physical test, such as a drained angle of repose shown in Figure 6. This simulation is of the current conveyor transfer with side and front views, which show the layout of the transfer and material behaviour. The aim of the figure is to demonstrate the nature of the particle dynamics experienced to help select and design calibration tests that best represent the large-scale flow behaviours.

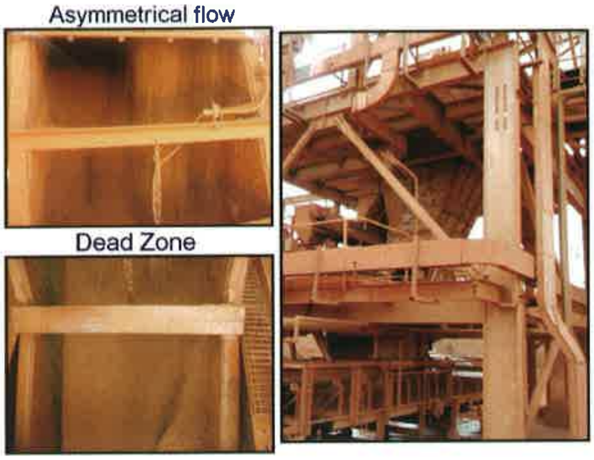


Figure 5: Transfer chute example.

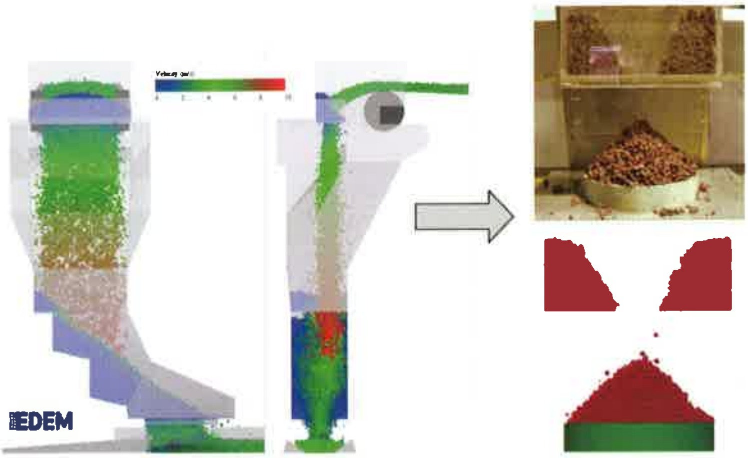

Figure 6: Rock-box chute design.

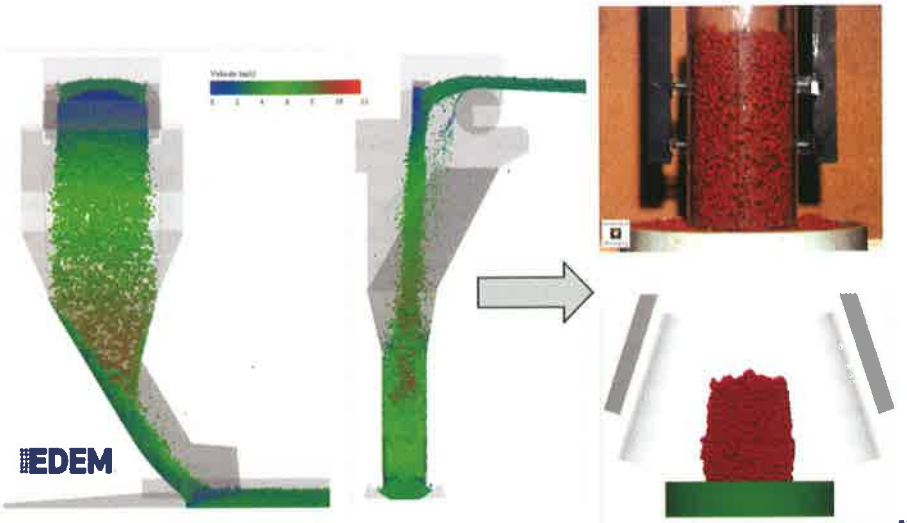

Figure 7: Spooned-chute design.

Figure 8: Bulk material-wall interactions (inclination test; large-scale wall friction test).

If we consider a spooned-chute design, the swing-arm slump test shown in Figure 7 is more representative of the rapid flow expected in the lower chute or spoon. Figure 8 below shows examples of inclination and wall friction tests that can be deployed to characterise the bulk material interaction with chute materials.

BMEA have also developed a variable-geometry conveyor transfer research facility, as shown in Figure 9, which is used to calibrate and validate DEM models. This facility can be modified to accommodate various geometry transfers and flow patterns/regimes, such as the hood-spoon and impact-plate shown in Figures 9 and 10. Additional validation can be performed with high-speed camera imaging, as shown in Figure 9.

In order to provide expert guidance and insight into the selection of appropriate physical tests, DEMSL have formed a joint venture with BMEA, which is a licensed consultancy of the University of Wollongong, Australia. The calibration methodology linking physical tests to EDEM is shown graphically in Figure 11. This approach has proved to work successfully, but at present, the conventional method for calibrating an EDEM model is to apply a manual process on a high-performance computer. This requires the user to define a wide variety of combinations of parameters and then perform assessments of the subsequent values that should be trialled. In many cases this involves a large number of simulations, which results in a very time consuming exercise. It is also important to recognise that due to the level of human interaction and the number of parameters that could be involved, it is very difficult to determine the effect of all the inter-parameter relationships taking place. As an example, how do the coefficient of restitution, the rolling friction and the static friction combine to affect the bulk behaviour?

DEMSL have addressed these issues by developing and implementing an automated parameter optimisation technique that will eliminate the need for user interaction to determine the parameters required for a material model. By implementing such algorithms, it is possible to eliminate manual intervention and automatically handle inter-parameter dependencies. The inevitable question then becomes how long will this new automated process take and will it still result in being a practical design method?

To further reduce the time required to reach the desired EDEM Material Model, DEMSL have also developed a grid computing method that allows multiple simulations to be performed simultaneously. Such an approach is highly scalable with the distributed computer power that is available. By deploying the optimisation on a cluster, or even a cloud computing system, it is possible to rapidly trial many hundreds of parameter combinations simultaneously. This means the whole calibration process can be performed in a matter of hours rather than weeks and months that can be required when performing a manual calibration process. This approach is also ideal for parameter sensitivity studies and geometry design analysis.

To provide an example of this optimisation approach, look at a case where

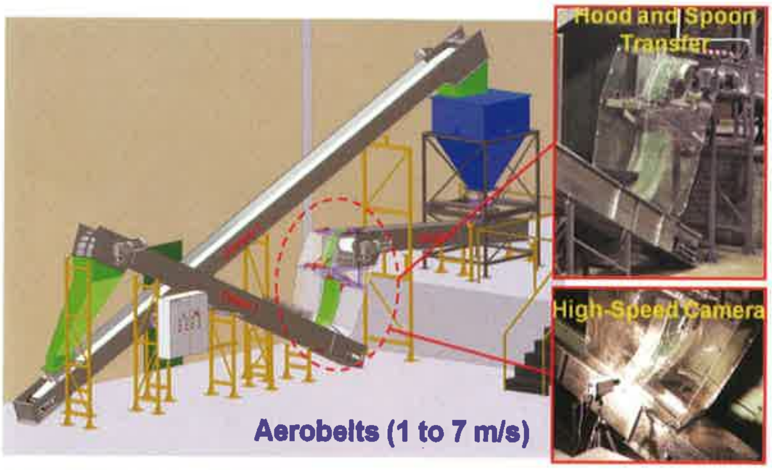


Figure 9: BMEA conveyor transfer research facility.

Figure 10: Impact-plate conveyor transfer.

DEM calibration is required to match an experimentally measured angle of repose for a given material. It is a simple task to take a sample of material and perform the necessary experimental measurements to obtain an angle of repose for the real material. The purpose of the optimisation is to adjust the DEM material properties such that the simulated repose angle is as close as possible to the experimental value.

The angle of repose of a material is not a standard output from a DEM simulation, and since one of the key premises of this process is that it is automated, DEMSL have developed an automated method for identifying the surface of the material heap and determining the angle of repose based on the surface particle position, as shown in Figure 12. This allows automatic extraction of a simulated result that can be compared with the experimental value. With this available information, the optimisation algorithm can be applied to begin solving the problem.

Continuing with the example above, performing the above optimisation on a single computer for a 1 hour simulation would take approximately 10,000 hours, or little over a year to complete. Introducing more specific optimisation algorithms to this single computer sees this time begin to reduce to somewhere around 1 month to complete. When the grid computing system is implemented, simulation time reduces further to around 630 compute hours. Using a standard 8-core cluster further reduces the overall simulation time to 3 to 4 days. This is a significant improvement on the year-long approach; however for industry a faster time-frame generally is still needed.

Running the angle of repose test with the optimised algorithm on a cloud system, such as the Microsoft Azure Cloud, the simulations can be solved in just a couple of hours. By replacing the manual methods with the automated, grid compute calibration approach a fit-for-purpose EDEM Material Model can be delivered in a short-time frame to the client enabling them to quickly begin investigating design options with confidence.

## 4. How much calibration is necessary?

This question can only be answered in the context of the engineering problem needing to be solved and by determining what would be classed as a reasonable technical risk. A Stage 0 model shown in Figure 13 based on "best guess" parameters will produce some insight but will unlikely provide the engineering accuracy needed to reduce technical risks in the overall design. Stage 1 calibration is normally an attempt to "tweak" the parameters so the overall flow looks "reasonable", but there is still no systematic matching with real material flow behaviour. Stage 2 calibration, which should be standard practice, is the methodology described in this document, where meticulous care is taken to choose appropriate physical tests that match the flow regime of the end application and calibrate the EDEM model accordingly.

## 5. Industrial applications

DEMSL has developed the grid-scale simulation techniques needed to use EDEM technology to match up with representative physical tests. BMEA provides the know-how in bulk materials engineering and advise which dynamic physical tests are appropriate to conduct. BMEA also has the facilities to conduct these tests and/or guide an on-site testing program. When we combine EDEM technology, DEM Solutions expertise, BMEA expertise and the commercial client's knowledge as shown

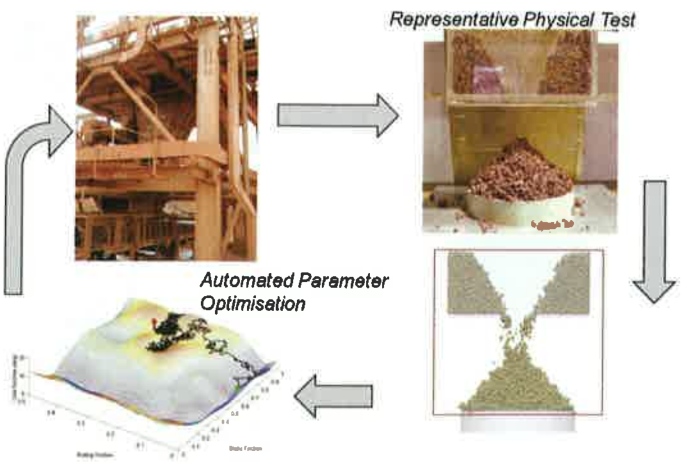


Figure 11: Linking the physical test to EDEM.

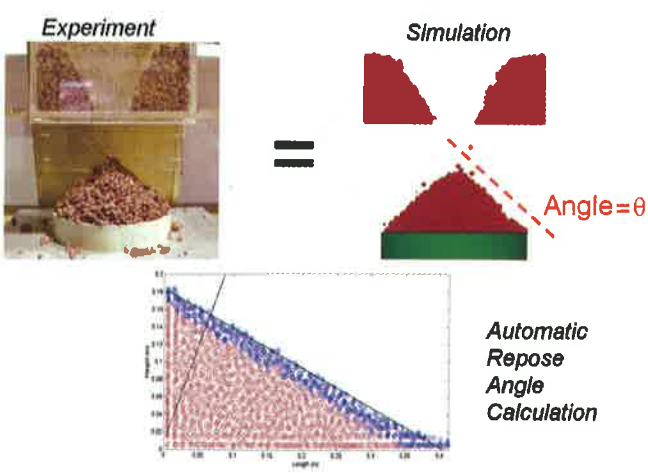


Figure 12: Parameter optimisation using angle of repose measurement.

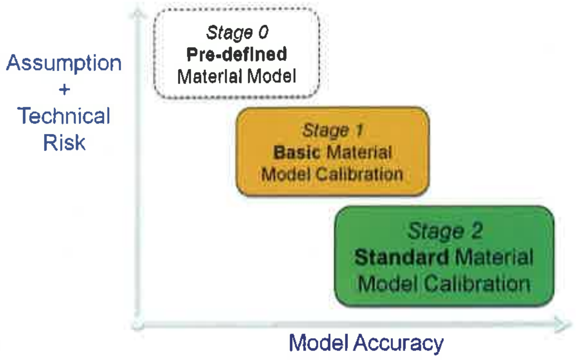


*Figure 13: Calibration – technical risk vs. model accuracy.*

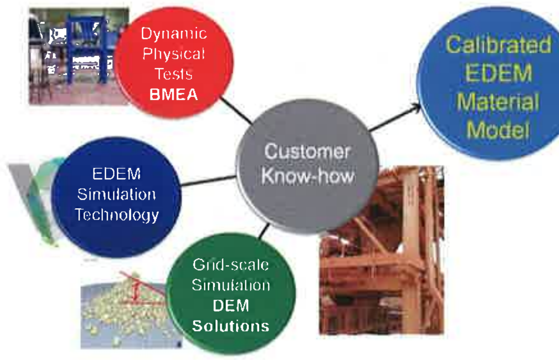


*Figure 14: EDEM Material Model calibration philosophy.*

in Figure 14, the result is a "fit-for-purpose" calibrated EDEM Material Model which will adequately represent the real bulk material flow. This resource and technology can then be used to design optimal bulk materials handling and processing plants.

## 6. Conclusions

It is very dangerous to assume or extrapolate anything when it comes to bulk material properties and behaviour. The consequences of making too many assumptions can be quite serious as illustrated by flow blockages in handling and processing operations, such as conveyor transfers, chutes, ship loading, etc.

Avoiding this problem, in the DEM computer simulation approach to design, can be achieved utilising a new optimised calibration technology which has been developed to adequately represent bulk material properties and flow behaviour. With new parameter optimisation techniques and the automated, grid computing approach, a fit-for-purpose EDEM Material Model can be delivered in a timeframe acceptable to industry.

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# HMA updates truck loading design

**As a result of a number of recent safety incidents across the country, Halley and Mellowes Australia's materials handling division has recently upgraded a number of existing truck loading facilities.**

*HMA's truck loading facility with double gate design.*

Upgrades are being commissioned to increase existing system safety levels and reduce the risks associated with loading trucks, such as cabin engulfment during the loading process.

HMA's design team developed a double gate design to provide a secondary means of isolation between product and personnel when entering the loading area. With client operational constraints in mind, the HMA design was fitted within the same envelope as the original loading gates to ensure no changes were required to the loading bin, structure or the trucks being used.

"Key to the design phase was the planning and consultation between all parties including drivers, maintenance personal, operations and management to ensure all had a chance to contribute and ensure that all possible loading issues were eliminated in our designs," said HMA product manager Luke Vidal.

"In conjunction with stakeholders, HMA also developed the hydraulic and control systems to automate the loading process, minimizing the risk of human error, and maximizing operational efficiencies."

HMA undertook detailed Safety Integrity Level (SIL) assessments to determine the SIL level required, with the HMA solution then verified prior to commencing construction.

"The identified SIL level required careful selection of critical control system hardware and the inclusion of multiple layers of protection; the final stage for HMA was to validate the system to ensure compliance with the SIL assessment outcomes, and all regulatory authorities," explained Vidal.

"All of these projects were undertaken on a turnkey basis with HMA providing all design, procurement, project management, installation and commissioning.

"The majority of the preliminary installations works for the projects were completed during normal site operation with the major change over and re-commissioning being undertaken in a normal two day plant shut down so operations were uninterrupted." ■

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